CHAPTER 4

EPA/NSF ETV EQUIPMENT VERIFICATION TESTING PLAN FOR THE REMOVAL OF RADON BY AIR-STRIPPING TECHNOLOGIES

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TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

Page

TABLES

LIST OF ABBREVIATIONS

ETV	Environmental Technology Verification
FOD	Field Operations Document
FTO	Field Testing Organization
gpm/sf	gallons per minute per square foot
MCL	Maximum Contaminant Level
mg/L	milligrams per liter
mrem/yr	milli-radiation equivalent man per year
NSF	NSF International
pCi/L	picocuries per liter
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control
rpm	revolutions per minute
% RSD	percent relative standard deviation
SDWA	Safe Drinking Water Act
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WSWRD	Water Supply and Water Resources Division

1.0 APPLICATION OF THIS NSF EQUIPMENT VERIFICATION TESTING PLAN

This document is the NSF Equipment Testing Verification Plan (ETV) for evaluation of air-stripping technologies to be used within the structure provided by NSF's "*Protocol for Equipment Verification Testing for the Removal of Radioactive Chemical Contaminants by Packaged and/or Modular Drinking Water Treatment Systems*". This Plan is to be used as a guide in the development of the Field Operations Document (FOD) for testing of air-stripping process equipment to achieve removal of radon.

In order to participate in the equipment verification process for air-stripping processes, the equipment Manufacturer and their designated Field Testing Organization (FTO) shall employ the procedures and methods described in this test plan and in the referenced NSF Protocol Document as guidelines for the development of a FOD. The FTO shall clearly specify in its FOD the radionuclides targeted for removal and sampling program that shall be followed during Verification Testing. The FOD should generally follow the Verification Testing Tasks outlined herein, with changes and modifications made for adaptations to specific membrane equipment. At a minimum, the format of the procedures written for each Task in the FOD should consist of the following sections:

- Introduction
- Objectives
- Work Plan
- Analytical Schedule
- Evaluation Criteria

The primary treatment goal of the equipment employed in this Verification Testing program is to achieve removal of radon present in feedwater supplies. The Manufacturer may wish to establish a Statement of Performance Capabilities (Section 3.0 General Approach) that is based upon removal of target radionuclides from feedwaters, or alternatively established one based upon compliance with drinking water standards. For example, the Manufacturer could include in the FOD a Statement of Performance Capabilities that would achieve compliance with maximum contaminant levels (MCLs) stipulated in the National Primary Drinking Water Standards or the EPA National Secondary Drinking Water Regulations for a specific water quality parameter. The experimental design of the FOD shall be developed to address the specific Statement of Performance Capabilities established by the Manufacturer. Each FOD shall include all of the included tasks, Tasks 1 to 8.

2.0 INTRODUCTION

Air-stripping processes are currently in use for a number of water treatment applications ranging from removal of hydrogen sulfide, volatile organic carbons, and radon.

In order to establish appropriate operations, the Manufacturer may be able to apply some experience with his equipment on a similar water source. This may not be the case for suppliers with new products. In this case, it is advisable to require a pre-test optimization period so that reasonable operating criteria can be established. This would aid in preventing the unintentional but unavoidable optimization during the Verification Testing. The need of pre-test optimization should be carefully reviewed with NSF, the FTO and the Manufacturer early in the process.

Pretreatment processes ahead of air-stripping systems may be required to remove particulate material and to ensure provision of high quality water to the air-stripping systems. In the design of the FOD, the Manufacturer shall stipulate which feedwater pretreatments are appropriate for application upstream of the air-stripping process. The stipulated feedwater pretreatment process(es) shall be employed for upstream of air-stripping process at all times during the Equipment Verification Testing Program.

3.0 GENERAL APPROACH

Testing of equipment covered by this Verification Testing Plan will be conducted by an NSF-qualified FTO that is selected by the equipment Manufacturer. Analytical water quality work to be carried out as a part of this Verification Testing Plan will be contracted with a laboratory certified by a State or accredited by a third-party organization (i.e., NSF) or the U.S. Environmental Protection Agency (USEPA) for the appropriate water quality parameters.

For this Verification Testing, the Manufacturer shall identify in a Statement of Performance Capabilities the specific performance criteria to be verified and the specific operational conditions under which the Verification Testing shall be performed. The Statement of Performance Capabilities must be specific and verifiable by a statistical analysis of the data. Statements should also be made regarding the applications of the equipment, the known limitations of the equipment and under what conditions the equipment is likely to fail or underperform. There are different types of Statements of Performance Capabilities that may be verified in this testing. Examples include two statements shown in Table 3.1:

During Verification Testing, the FTO must demonstrate that the equipment is operating at a steady-state prior to collection of data to be used in verification of the Statement of Performance Capabilities. For each Statement of Performance Capabilities proposed by the FTO and the Manufacturer in the FOD, the following information shall be provided:

- percent removal of the targeted radionuclide;
- rate of treated water production;
- recovery;
- feedwater quality regarding pertinent water quality parameters;
- temperature;
- concentration of target radionuclide; and
- other pertinent water quality and operational conditions.

This NSF Equipment Verification Testing Plan is broken down into 8 tasks, as shown in the Section 6.0, Overview of Tasks. These Tasks shall be performed by any Manufacturer wanting the performance of their equipment verified by NSF. The Manufacturer's designated FTO shall provide full detail of the procedures to be followed in each Task in the FOD. The FTO shall specify the operational conditions to be verified during the Verification Testing Plan.

Table 3.1: Example Statements of Performance Capabilities for Radon Removal

Type of Statement of Performance Capabilities	Example of Statement of Performance Capabilities
Radon Removal	This packaged plant is capable of achieving 90 percent removal of radon during a 60-day operation period at an air to water ratio of 30, and a water loading rate of 25 gal/sf-min (temperature between 20 and 25 °C) in feedwaters with radon concentrations less than 500 pCi/L and total hardness concentrations less than 150 mg/L.
Regulatory Compliance	NA*

* Radon regulation anticipated in August 2000.

4.0 BACKGROUND

This section provides an overview of the literature review related to radionuclide regulations, health effects, and contaminant removal by air-stripping technologies, and air-stripping technology design. These items will assist in the following:

- Defining various air-stripping technologies capable of removing radon;
- Defining air-stripping technologies; and
- Describing the mechanisms that will help in qualifying and quantifying the removal efficiency of the air-stripping technology tested.

4.1 Regulatory Review and Health Effects

The passage of the Safe Drinking Water Act of 1974 (SDWA) required the establishment of recommended maximum contaminant levels (MCLs) for compounds that were deemed undesirable for consumption in public water supplies. Since that time there has been a growing awareness of the need for the control and removal of chemical contaminants from potable drinking water supplies. The 1986 Safe Drinking Water Act (SDWA) Amendments authorized the National Primary Drinking Water Regulations and required that the USEPA set such regulations on 83 contaminants including radionuclides.

Currently, radon is not regulated. USEPA will propose a radon MCL in August 2000. This equipment verification test will evaluate various technologies for the removal of radon.

In July 1991 the USEPA proposed a new rule for radionuclides in drinking water supplies (Federal Register Citation 56 GR 33050, Phase III Rule). More than 600 public comments submitted on the proposed rule were evaluated by the USEPA. Although a court deadline of April 1993 existed for the issuance of the final rule, the USEPA has delayed this deadline due to resource constraints.

The Phase III Rule withdrew the radon MCL. USEPA is expected to propose a radon MCL in August 2000. In order to minimize risks to human health, the exposure levels to these compounds must be reduced to the lowest level that is both technologically and economically feasible.

The chronic health hazards associated with the presence of radionuclides in drinking water have become a major concern of United States governmental agencies in more recent times. Diseases that may be associated with radon in drinking water include stomach cancer from ingestion of drinking water, and lung cancer from inhalation of radon decay products released during household use of water. Associations of radon with other forms of cancer are considered negligible.

4.2 Definitions for Various Radionuclides

4.2.1 Radon

Radon (Rn) is a naturally occurring noble gas that is an alpha emitting radionuclide. Radon is a chemically inert decay product of the uranium series and is the immediate decay product of Ra-226. Radon is a noble gas, very mobile, and has a short half-life of just less than four days. Radon is only found in groundwater sources of water supply since it originates in the ground and naturally degasses from surface waters. The activity of radon in water and air is generally higher than that of other radionuclides. Radon in the public water supply enters a customer's home through the distribution system and is released into the indoor air when the water is used for household purposes such as washing and cleaning. Radon is removed using air-stripping processes. As mentioned previously, there is currently no MCL for radon.

4.2.2 Removal Processes

Water supply systems that use sources that contain radionuclide concentrations above future MCLs will need to implement treatment techniques to comply with future regulations. Treatment processes that are available for the removal of radon include, but are not limited to, adsorptive media and air stripping.

This Plan discusses the use of air-stripping technologies for the removal of radon. Air-stripping is a water treatment technique utilized for the removal of contaminant gases from water. Since radon is the only radionuclide that is a naturally occurring gas, this Plan will be directed towards the removal of radon. The following section discusses the various air-stripping technologies available for the removal of radon.

4.3 Radon Removal by Air-Stripping Technologies

Aeration or air-stripping involves the transfer of radon from the water phase to the gas phase. The mass transfer from the liquid phase to the gas phase occurs over the liquid-gas interface in the direction of decreased concentration. There are two main classifications of aeration. They include gas dispersion in water and water dispersion in gas. Diffused aeration is an example of gas dispersion in water, and packed tower aeration is an example of water dispersion in gas.

One of the most integral components to the selection and design of an air-stripping device for the removal of a contaminant is Henry's constant for that contaminant. Henry's Law states that when gas and water are at equilibrium, the concentration of a substance in the gas phase is proportional to the concentration of the substance in the liquid phase. Therefore, the greater the proportional constant of a gas, the more easily that gas can be removed from solution by air stripping. This is because the mass transfer of gas moves in the direction of decreased concentration until an equilibrium state is reached. Conversely, those gases with a low proportional constant of the gas tend to accumulate in the aqueous phase. This proportional constant is known as Henry's constant.

Henry's constant for radon is estimated to be 2,600 in water at 20^{o}C and 1 atm of pressure. This constant is considered relatively high, and therefore, the removal of radon from a raw water supply using air stripping should occur fairly quickly. Henry's constants for radon and other common gases are listed in Table 4.1. Henry's constants may vary greatly with temperature and therefore testing or operating conditions should be reviewed carefully when designing air-stripping equipment.

TABLE 4.1: Henry's Constants for Selected Gases in Water at 20^{o}C and 1 atm of Pressure

Gas	Henry's Constant (atm)
Radon	2,600
Vinyl Chloride	355,000
Oxygen	43,000
Carbon Dioxide	1,510
Chlorine	585
Hydrogen Sulfide	515
Benzene	240
Chloroform	170
Bromoform	35

The efficiency of radon removal by air stripping will depend primarily on the air to water flow rate ratio, the mass transfer coefficient and the water temperature, and to a lesser extent on the air temperature. Water treatment by aeration has been historically utilized for the removal of volatile organic carbon, carbon dioxide and hydrogen sulfide. It is also considered a cost effective treatment method for the removal of radon from drinking water supplies. There are several types of air-stripping technologies that are available for the removal of radon. They are as follows:

- packed tower aeration;
- multistaged diffused bubble aeration;
  - spray jet aeration
  - tray aeration
  - spray aeration
- induced-draft towers; and
- venturi in-line devices.

The technologies that are described in this plan include packed tower aeration, multistaged diffused bubble aeration, and spray jet aeration. These air-stripping technologies are typically followed by chemical injection for disinfection.

4.3.1 Packed Tower Aeration

Packed tower aeration is an example of water dispersion in gas. Packed towers are generally vertical cylindrical columns. Mass transfer in a packed tower is achieved by counter-current or co-current flow, with counter-current flow being more effective. With counter-current flow raw water is pumped to the top of the tower(s) and cascades by gravity over the surface of the packing. At the same time, air is forced into the bottom of the tower and blown upward through the packing. The tower packing can be fixed or randomly packed media of various shapes, sizes, and material. The packing material disrupts the flow of water into small droplets, and therefore continually generates air-water interfaces. Air-stripping towers have been found to be most applicable for water treatment facilities with flows greater than 300 to 500 gpm, but can be also applicable at lower flows.

The water is collected at the bottom of the column in a clearwell, and then pumped to subsequent treatment facilities, or disinfected for distribution. The gasses that are blown off from the tower are discharged to the atmosphere since it is not feasible to treat radon in the air stream. This would depend on the concentration of radon and other undesirable gases in the raw water source, and the local regulations that govern the release of hazardous or odiferous gases to the atmosphere. Tower height may be a major disadvantage to the packed tower technology if the facilities require significant tower height, and are located in residential areas.

4.3.2 Multistaged Bubble Aeration

Multistaged bubble aeration is a form of diffused aeration. These aeration devices are compact and have lower profiles than packed towers. The facilities consist of a vessel with several compartment stages. Water enters the box horizontally as air is diffused from aerators on the bottom of each stage. The diffusers are designed to provide uniform distribution of air.

The aeration vessels are typically equipped with a removable top for cleaning and maintenance. The blowers are generally mounted on a nearby wall or on the floor. The gasses that are vented from the diffused aeration process can be discharged to the atmosphere. These aerators are typically most applicable for smaller flows less than 1,000 gpm.

4.3.3 Spray Jet Aeration

Jet aeration is a diffused aeration process that combines liquid pumping with air diffusion. Jet aeration can be provided in a reservoir, tank or tower. Proper air dispersion and water distribution is integral to proper design of this air-stripping technology. The liquid pumping system recirculates the water in the given basin while injecting it with compressed air through a nozzle assembly. The spray jet unit provides for the water to enter the jet nozzle unit at right angles to the body of the unit through carefully designed orifices. This creates a vacuum effect through the rear of the unit. The jet aerator produces a pressurized water stream that results in a violent mixing of the water and air within the spray jet unit, resulting in the stripping of gases. Design of these type aerators will greatly depend on manufacturer data and information regarding the jet aerator units.

Modifications to jet aeration technology can include the varying of flow rates to provide varying air to water ratios. Adjusting the size of the orifices on the jet aerator does this. Spray jet aerators may also operate in single or multiple pass modes where the water supply can be passed through the aerator from one to several times.

4.4 Air-Stripping Technology Design Considerations

Although the equipment for the various air-stripping technologies vary greatly, the design considerations for the technologies are similar. These design considerations include, but are not limited to:

- Water and air flow rates
- Surface area at the water/air interface (mass transfer coefficient)
- Water and air temperature
- Henry's constant for radon
- Water quality

Pretreatment, prior to air-stripping may be necessary to provide removal of iron, manganese, or to reduce the scaling potential. Also, calcium carbonate scaling with the removal of carbon dioxide is a potential problem with aeration applications.

4.4.1 Packed Tower Aeration

The major design components to be considered for packed tower aerators include:

- volumetric air-water ratio;
- water and air loading rates;
- packing material;
- size and depth;
- column diameter;
- gas pressure drop; and
- Henry's constant of the contaminant(s) to be removed.

The air to water ratio can range from 10:1 to 5,000:1 for gas stripping techniques. For the removal of radon, typically an air to water ration will range from 10:1 to 30:1. However, the air to water ratio may be more limited or constrained by the removal of another contaminant from the raw water supply. Hydraulic loading rates for the removal of radon typically range from 20 to 30 gallons per minute per square foot (gpm/sf). Air delivery can be accomplished using forced draft or induced draft aeration.

The packing material should be designed to provide a maximum amount of surface area for water to contact. At the same time the material should be chosen and designed to minimize impedance to the air flow. Random media can be shaped as discs, spheres, or barrels, while structured packing generally consists of rigid plastic sheets fused together. The packing material may require periodic cleaning with acid depending on the raw water quality. A packing support plate is used to hold the packing material in place.

Tower design can be aided by the use of mass transfer equations. Literature research documents the use of relating packing height (Z), height of transfer unit (HTU), number of transfer units (NTU), and stripping factors (R) for packed tower design. HTU is a measurement of the mass transfer efficiency, NTU is a measurement of the movement of a compound in solution to the gas phase, and R represents an equilibrium parameter. These relationships assume steady-state operations, dilute solutions, and chemical equilibria.

Tower diameter and pressure drop for a packed tower can be estimated using pressure drop curves as developed by Eckert. The curves by Eckert relate pressure drop to gas and liquid loading rates. There has also been arithmetic representation of the Eckert plot performed by Prahl. These graphical and arithmetic aids are useful in the design of packed towers. There are also several computer programs available for the sizing of packed tower aerators.

Henry's constant for radon, which was previously discussed, can be used to determine the rate of transfer from water into clean air. Therefore, Henry's constant is an important design parameter that should be considered for the design of packed towers. It should be noted that published values of Henry's constant for radon may vary based on the constant's dependence on temperature.

4.4.2 Multistaged Bubble Aeration

The design of a multistaged bubble aeration system is based on mass transfer efficiency. This design utilizes the air to water ratio, water depth, and diffuser orifice size. A typical air to water ratio for radon removal with multistaged bubble aeration is 6:1 to 30:1, depending on the amount of removal desired. The power usage for this diffused system will be greater than that of an air stripper, because the air is discharged under pressure to the diffusers submerged in water.

The number and spacing of diffusers is generally determined based on the capacity of an individual diffuser, the geometry of the basin, and the desired level of mixing necessary for contaminant removal. Diffused multistaged aeration units can be manifolded for the treatment of larger capacities

4.4.3 Spray Jet Aeration

The design of spray aeration devices may be approached using the mass transfer coefficient and the transfer unit approach discussed for packed tower aeration. This method, however, is not completely valid as the mass transfer coefficient that is used represents an average value based on basin or tower height. Therefore, design of a spray jet aeration system cannot be performed for precise removal. However, the design approach using the average mass transfer coefficient may be used to approximate spray aeration removal efficiency.

The manufacturer should provide flow capacities for the jet nozzles for a large range of pressure drops and orifice sizes. The flow rate through a nozzle is proportional to the square root of the pressure. Spray jet nozzles may be prone to clogging and erosion corrosion.

The design of the spray chamber should consider the orientation and location of the air inlets. The inlets should be designed to avoid high inlet velocities and turbulence. If air velocities are too high there may be a substantial loss of water in the system. Mist eliminators can be used to reduce liquid loss in the chamber. The chamber is typically designed for a pressure loss of approximately 1 inch of water.

5.0 DEFINITION OF OPERATIONAL PARAMETERS

The following terms are presented here for subsequent reference in this test plan:

- **Equipment** - A package drinking water treatment system or a modular component of a package drinking water system.

- **Manufacturer** - A business that makes and/or sells package plant equipment and/or modular systems. The role of the manufacturer is to provide the package plant and/or modular system and technical support during the verification testing and study. The manufacturer is also responsible for providing assistance to the field testing organization during operation and monitoring of the package plant or modular system during the verification testing and study.

- **Field Testing Organization** - An organization qualified to conduct studies and testing of package plants or modular systems in accordance with protocols and test plans. The role of the field testing organization is to complete the application on behalf of the Company; to enter into contracts with NSF, as discussed herein; and arrange for or conduct the skilled operation of a package plant during the intense periods of testing during the study and the tasks required by the Protocol.

- **Modular System -** A packaged functional assembly of components for use in a drinking water treatment system or packaged plant, each part of which provides a limited form of treatment of the feed water(s) and which is discharged to another packaged plant or the final step of treatment.

- **Multistaged Bubble Aeration -** An air-stripping technology that includes the injection of gas bubbles into a column or tank of water to produce intense mixing, resulting in the stripping of gases.

- **NSF -** NSF International, its staff, or other authorized representatives.

- **NSF Equipment Verification Testing Plan** - A specific testing plan for each packaged plant technology application, such as systems employing cation and anion exchange, adsorptive media, reverse osmosis, and air-stripping for the removal of radioactive chemical contaminants. This plan will be developed by NSF for the Manufacturer to assist in development of the FOD for the Verification Testing Project.

- **Package Plant** - A complete water treatment system including all components from the connection to the raw water(s) intake through discharge to the distribution system.

- **Packed Tower Aeration –** An air-stripping technology that includes the production of thin films or small droplets of water that yield rapid mass transfer, resulting in the stripping of gases.

- **Protocol** - A written document that clearly states the objectives, goals and scope of the study as well as the test plan(s) for the conduct of the study. The protocol shall be used for reference during manufacturer participation in verification testing project.

- **Spray Jet Aeration** - An air-stripping technology that includes an aerator that produces a pressurized water stream that results in a violent mixing of the water and air within the spray jet unit, resulting in the stripping of gases.

- **Testing Organization** - An organization qualified to perform studies and testing of package or modular systems. The role of the testing organization is to ensure that there is skilled operation of a package plant during the intense periods of testing and that all of the tasks required by the Study Protocol for Equipment Verification Testing are performed properly. The Testing Organization is responsible for:

  ⇒ Managing, evaluating, interpreting and reporting on the data produced by the verification testing and study.

  ⇒ Providing logistical support, scheduling and coordinating the activities of all participants in the verification testing and study, i.e., establishing a communications network.

  ⇒ Advising the Manufacturer on feed water quality and test site selection, such that the locations selected for the verification testing and study have feed water quality consistent with the objectives of the Study Protocol for Equipment Verification Testing.

- **Testing Plan** - A written document that describes the procedures for conducting a test or study for the application of water treatment technology. At a minimum, the test plan will include detailed instructs for sample and data collection, sample handling and sample preservation, precision, accuracy, and reproducibility goals, and quality assurance and quality control requirements.

- **Testing Laboratory** - An organization certified by a third- party independent organization, federal agency, or a pertinent State regulatory authority to perform the testing of drinking water samples. The role of the testing laboratory in the verification testing of package plants and/or modular systems is to analyze the water samples in accordance with the methods and meet the pertinent quality assurance and quality control requirements described in the protocol and test plan field operations document.

- **USEPA** - The United States Environmental Protection Agency, its staff or authorized representatives.

6.0 OVERVIEW OF TASKS

This Plan is applicable to the testing of package water treatment equipment utilizing air-stripping technologies that include spray jet, multistage diffused bubble and packed tower aeration. Testing of air stripping equipment will be conducted by a NSF-qualified Testing Organization that is selected by the Manufacturer. Water quality analyses will be performed by a state-certified or third party- or EPA-accredited laboratory. This Plan provides objectives, work plans, schedules, and evaluation criteria for the required tasks associated with the equipment testing procedure.

The following is a brief overview of the tasks that shall be included as components of the Verification Testing Program and FOD for removal of radon.

- **Task 1: Equipment Verification Testing Plan –** Operate air-stripping and associated water treatment equipment for a 60-day testing period to collect data on water quality and equipment performance.
- **Task 2: Characterization of Raw Water –** Obtain chemical, biological and physical characterization of the raw water. Provide a brief description of the groundwater source that provides the raw water to the water treatment plant.
- **Task 3: Operations and Maintenance (O&M)** - Evaluate an O&M manual for each system submitted. The O&M manual shall characterize air-stripping process design.
- **Task 4: Data Collection and Management –** Establish an effective field protocol for data management between the Field Testing Organization and NSF.
- **Task 5: Radon Removal -** Evaluate air-stripping technology operations in relation to verified raw water quality.
- **Task 6: Finished Water Quality –** Evaluate the water quality produced by the air-stripping technology as it relates to raw water quality and operational conditions.
- **Task 7: Quality Assurance / Quality Control (QA/QC) –** Develop a QA/QC protocol for Verification Testing. This is an important item that will assist in obtaining an accurate measurement of operational and water quality parameters during aeration equipment Verification Testing.
- **Task 8: Cost Evaluation** - Develop O&M costs for the submitted air-stripping technology and package plant.

7.0 TESTING PERIODS

The required tasks of the NSF Equipment Verification Testing Plan (Tasks 1 through 8) are designed to be completed over a 60-day period, not including mobilization, shakedown and start-up. The schedule for equipment monitoring during the 60-day testing period shall be stipulated by the FTO in the FOD, and shall meet or exceed the minimum monitoring requirements of this testing plan. The FTO shall ensure in the FOD that sufficient water quality data and operational data will be collected to allow estimation of statistical uncertainty in the Verification Testing data, as described in the "*Protocol for Equipment Verification Testing of for Removal of Radioactive Chemical Contaminants*". The FTO shall therefore ensure that sufficient water quality and operational data is collected during Verification Testing for the statistical analysis described herein.

For air-stripping process treatment equipment, factors that can influence treatment performance include:

- Air to water flow rate ratio;
- Calcium carbonate scaling due to removal of carbon dioxide; and
- High concentrations of iron or manganese.

Air-stripping testing conducted beyond the required 60-day testing may be used for fine-tuning of air-stripping performance or for evaluation of additional operational conditions. During the testing periods, evaluation of finished water quality can be performed concurrent with air-stripping operation testing procedures.

8.0 TASK 1: EQUIPMENT VERIFICATION TESTING PLAN

8.1 Introduction

The equipment verification for air-stripping technologies for radon removal shall be conducted by an NSF-qualified, Field Testing Organization (FTO) that is selected by the Manufacturer. Water quality analytical work to be completed as a part of this NSF Plan shall be contracted with a state-certified or third party- or EPA- accredited laboratory. For information on a listing of NSF-qualified FTOs and state-certified or third party- or EPA- accredited laboratories, contact NSF.

8.2 Objectives

The objective of this task is to operate the equipment provided by a Manufacturer, for the conditions and time periods specified by NSF and the Manufacturer.

8.3 Work Plan

8.3.1 Equipment Verification Test Plan

Table 8.1 presents the Tasks that are included in this Plan and will be included in the FOD for radon removal by air stripping technologies. Any Manufacturer wanting to verify the performance of their equipment shall perform these Tasks. The Manufacturer shall provide full detail of the procedures to be followed for each item in the FOD. The FTO shall specify the operational conditions to be verified during the Verification Testing.

In the design of the FOD, the FTO shall stipulate which pretreatments are appropriate for application before the selected air-stripping processes. The recommended pretreatment process(es) shall then be employed by the Manufacturer for raw water pretreatment during implementation of the Equipment Verification Testing Program.

TABLE 8.1: Task Descriptions

No.	Task	Description
1	Test Plan	Water treatment equipment shall be operated for a minimum of one 60 day test period to collect data on water quality and equipment performance.
2	Characterization of Raw Water	Obtain chemical, biological and physical characterization of the raw water.
3	O&M Manual	Evaluate O&M manual for process.
4	Data and Collection Management	Develop data protocol between FTO and NSF.
5	Radon Removal	Evaluate radon removal at selected set of operational conditions.
6	Finished Water Quality	Evaluate water quality at selected set of operational conditions.
7	QA/QC	Enforce QA/QC standards.
8	Cost Evaluation	Provide O&M costs of system.

8.3.2 Routine Equipment Operation

During the time intervals between equipment verification runs, the package water treatment equipment may be used for production of potable water. If the equipment is being used for the production of potable water, routine operation for water production is expected. In addition, the equipment should not be used for potable water production should a finished water quality parameter not comply with the requirements of the National Primary Drinking Water Standards or the EPA National Secondary Drinking Water Regulations. The operating and water quality data collected and furnished to the local regulatory agency should also be supplied to the NSF-qualified FTO.

8.4 Analytical Schedule

The entire equipment verification shall be performed over a 60-day period (not including time for system shakedown and mobilization). At a minimum, one, 60-day period of Verification Testing shall be conducted in order to provide equipment testing information for air-stripping technology performance.

The required tasks for the equipment verification are designed to be completed over a 60-day period, not including mobilization, shakedown and start-up. Air-stripping technology testing conducted beyond the required 60-day testing may be used for fine-tuning of air-stripper performance or for evaluation of additional operational conditions. During the 60-day testing period, evaluation of finished water quality can be performed concurrent with the percent removal testing procedures.

8.5 Evaluation Criteria

The equipment testing period will include a Verification Test of at least 60-days. If package water treatment equipment is also operated for potable water production, the data supplied to the FTO shall be evaluated with regard to compliance with National Primary Drinking Water Standards or EPA National Secondary Drinking Water Regulations.

9.0 TASK 2: CHARACTERIZATION OF RAW WATER

9.1 Introduction

The characterization of raw water quality is needed to determine if the concentrations of radon or other raw water contaminants are appropriate for the use with air-stripping technologies. The feedwater quality can influence the performance of the equipment as well as the acceptance of testing results by Federal and State regulatory agencies.

9.2 Objectives

One reason for performing a raw water characterization is to obtain at least one-year of historical raw water quality data from the raw water source. The objective is to:

- develop maximum and minimum concentrations for the contaminant; and
- develop a probable percentage of removal necessary to meet the proposed MCL.

If historical raw water quality is not available, a raw water quality analysis of the proposed feedwater shall be performed prior to equipment Verification Testing.

9.3 Work Plan

The characterization of raw water quality is best accomplished through the performance of laboratory testing and the review of historical records. Sources for historical records may include municipalities, laboratories, USGS (United States Geological Survey), USEPA, and local regulatory agencies. If historical records are not available preliminary raw water quality testing shall be performed prior to equipment Verification Testing. The specific parameters of characterization will depend on the air-stripping equipment that is being tested. The following characteristics should be reviewed and documented:

- Temperature
- pH
- Hardness
- Alkalinity
- Iron and manganese
- Radon
- Volatile Organic Contaminants
- Bacteria
- Other dissolved gases such as CO_2 and hydrogen sulfide

The data that is collected will be shared with NSF so that the FTO can determine the significance of the data for use in developing a test plan. If the raw water source is not characterized the testing program may fail, or results of a testing program may not be considered acceptable. A description of the raw water source should also be included with the feedwater characterization. The description may include items such as:

- nature of the water source; and
- potential sources of pollution.

9.4 Schedule

The schedule for compilation of adequate water quality data will be determined by the availability and accessibility or historical data. The historical water quality data can be used to determine the suitability of various air stripping technologies for the treatment for the raw source water. If raw water quality data is not available, a preliminary raw water quality testing should be performed prior to the verification testing of the aeration equipment.

9.5 Evaluation Criteria

The feedwater quality shall be evaluated in the context of the Manufacturer's Statement of Performance Capabilities for the removal of radon. The feedwater should challenge the capabilities of the chosen equipment, but should not be beyond the range of water quality suitable for treatment by the chosen equipment. For air-stripping processes, a complete scan of water quality parameters may be required in order to determine pretreatment criteria.

10.0 TASK 3: OPERATIONS AND MAINTENANCE MANUAL

An operations and maintenance (O&M) manual for air-stripping technology to be tested for radon removal shall be included in the Verification Testing evaluation.

10.1 Objectives

The objective of this task is to develop an O&M manual that will assist in operating, troubleshooting and maintaining the air-stripping system performance. The O&M manual shall:

- characterize air stripping technology design;
- outline air stripping procedures;
- air to water ratios;
- cleaning procedures; and
- provide a radon gas safety control plan (e.g. ventilation).

Criteria for evaluation of the equipment's O&M Manual shall be compiled and then evaluated and commented upon during verification by the FTO. An example is provided in Table 10.1.

The purpose of O&M information is to allow utilities to effectively choose a technology that their operators are capable of operating, and provide information on how many hours the operators can be expected to work on the system. Information about obtaining replacement parts and ease of operation of the system would also be valuable.

10.2 O&M Work Plan

Descriptions of air-stripping technology unit process design shall be developed for the removal of radon. Air-stripping technologies shall include the design criteria and equipment characteristics. Examples of information required relative to the air-stripping design criteria and characteristics are presented in Tables 10.2 and 10.3, respectively.

Depending on the raw water quality, chemical cleaning of the air-stripping equipment may be required. Cleaning will be performed as necessary per manufacturer specifications. Packing material for a packed tower aerator may require periodic replacement. Chemical cleaning and material replacement should be noted so that it may be considered for the verification of the equipment.

TABLE 10.1: NSF Operations & Maintenance Manual Criteria - Air-Stripping Package Plants

MAINTENANCE:
The manufacturer should provide readily understood information on the recommended or required maintenance schedule for each piece of operating equipment such as: • flow meters • pumps • motors • valves • air filters • chemical feeders (pretreatment) • blowers, jet aerators, course bubble diffusers The manufacturer should provide readily understood information on the recommended or required maintenance for non-mechanical or non-electrical equipment such as: • air-stripping process • packing material • piping
OPERATION:
The manufacturer should provide readily understood recommendation for procedures related to proper operation of the package plant equipment. Among the operating aspects that should be discussed are: Chemical feeders (pretreatment): • calibration check • settings and adjustments - how they should be made • dilution of chemicals - proper procedures Monitoring and observing operation: • removal calculations

TABLE 10.1: NSF Operations & Maintenance Manual Criteria - Air-Stripping Package Plants (continued)

OPERATION (continued):

The manufacturer should provide a troubleshooting guide; a simple check-list of what to do for a variety of problems including:

- packed tower flooding;
- no pretreatment chemical feed;
- media clogging
- automatic operation (if provided) not functioning;
- no electric power; and

The following are recommendations regarding operability aspects of package plant air-stripping technology processes. These aspects of plant operation should be included to the extent practical in reports of package plant testing when the testing is done under the NSF Verification Program. During Verification Testing, attention shall be given to package plant operability aspects.

- are chemical feed pumps calibrated?
- is the air pressure at the blower discharge calibrated?
- are air flow meters calibrated?
- are pH meters calibrated?
- are water flow meters calibrated?
- can cleaning be done automatically?
- does remote notification occur (alarm) when pressure increases > 15% or flow drops > 15%?

The reports on Verification Testing should address the above questions in the written reports. The issues of operability should be dealt with in the portion of the reports that are written in response to Operating Conditions and Treatment Equipment Performance, in the Air Stripping Technology Test Plan.

TABLE 10.2: Air-Stripping Technology Design Criteria Reporting Items

Parameter	Unit
Type of unit	
Number of units	
Average flow rate (gpm)	
Maximum water flow rate to unit (gpm)	
Minimum water flow rate to unit (gpm)	
Maximum air flow rate to unit (cfm)	
Minimum air flow rate to unit (cfm)	
Air to water ratio (calculated)	
Surface area at the air/water interface (sf) (Packed Tower)	
Water temperature (^oC)	
Air temperature (^oC)	
Raw water radon concentration (pCi/L)	
Treated water radon concentration (pCi/L)	
Percent removal of radon (%)	

TABLE 10.3: Air-Stripping Equipment Characteristics

Parameter	Unit
Technology Manufacturer	
Equipment model number	
Diffuser type or packing material type	
Active surface area (sf) (Packed Tower)	
Design hydraulic loading rate (gpm/sf) (Packed Tower)	
Design air to water ratio	
Standard testing removal (%)	
Standard testing pH	
Standard testing temperature (°C)	
Design concurrent flow velocity (fps)	
Maximum flow rate to the unit (gpm)	
Minimum flow rate to the unit (gpm)	
Acceptable range of water quality parameters	
Pumping requirements	
Blower Requirements	
Suggested cleaning procedures	
Suggested equipment replacement schedule	
Type of construction	
Estimated Purchase Price	
Other	

Note: Some of this information may not be available, but this table should be filled out as completely as possible for each technology tested

11.0 TASK 4: DATA COLLECTION AND MANAGEMENT

11.1 Introduction

The data management system used in the Verification Testing Program shall involve the use of computer spreadsheets, and manual recording of operational parameters for the air-stripping equipment on a daily basis.

11.2 Objectives

The objective of this task is to establish a viable structure for the recording and transmission of field testing data such that the FTO provides sufficient and reliable operational data for the NSF for verification purposes. Chain-of-Custody protocols will be developed and adhered to.

11.3 Work Plan

11.3.1 Operation Data Collection and Documentation

The following protocol has been developed for data handling and data verification by the FTO. In addition to daily operational data sheets, a Supervisory Control and Data Acquisition (SCADA) system could be used for automatic entry of pilot-testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters should then be downloaded by manual importation into electronic spreadsheets. These specific database parcels shall be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data shall be manipulated into a convenient framework to allow analysis of air-stripping equipment operation. At a minimum, backup of the computer databases to diskette should be performed on a monthly basis.

Field testing operators shall record data and calculations by hand in laboratory notebooks for a minimum of three times per day. (Daily measurements shall be recorded on specially prepared data log sheets as appropriate. Figure 12.2 presents an example of a daily log sheet.) The laboratory notebook shall provide copies of each page. The original notebooks shall be stored on-site; the copied sheets shall be forwarded to the project engineer of FTO at least once per week during the 60-day testing period. This protocol will not only ease referencing the original data, but offer protection of the original record of results. Pilot operating logs shall include:

- descriptions of the equipment and test runs;
- names of visitors; and
- descriptions of any problems or issues.

Such descriptions shall be provided in addition to experimental calculations and other items.

11.3.2 Data Management

The database for the project shall be set up in the form of custom designed spreadsheets. The spreadsheets shall be capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the field laboratory analysis notebooks and data log sheets shall be entered into the appropriate spreadsheet. Data entry shall be conducted on-site by the designated field testing operators. All recorded calculations shall also be checked at this time.

Following data entry, the spreadsheet shall be printed and the print-out shall be checked against the handwritten data sheet. Any corrections shall be noted on the hardcopies and corrected on the screen, and then the corrected recorded calculations will also be checked and confirmed. The field testing operator or engineer performing the entry or verification step shall initial each step of the verification process.

Each experiment (e.g. each air-stripping technology test run) shall be assigned a run number, which will then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to state-certified or third party- or EPA- accredited laboratories, the data shall be tracked by use of the same system of run numbers. Data from the outside laboratories shall be received and reviewed by the FTO. This data shall be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

11.3.3 Statistical Analysis

For the analytical data obtained during Verification Testing, 95% confidence intervals shall be calculated by the FTO for selected water quality parameters. The specific Plans shall specify which water quality parameters shall be subjected to the requirements of confidence interval calculation. As the name implies, a confidence interval describes a population range in which any individual population measurement may exist with a specified percent confidence. When presenting the data, maximum, minimum, average and standard deviation should be included.

Calculation of confidence intervals shall not be required for equipment performance obtained during the equipment Verification Testing Program. In order to provide sufficient analytical data for statistical analysis, the FTO shall collect three discrete water samples at one set of operational conditions for each of the specified water quality parameters during a designated testing period.

12.0 TASK 5: RADON REMOVAL

12.1 Introduction

The removal of radon gas from drinking water supplies is accomplished by air-stripping treatment. The effectiveness of radon removal by diffused air and packed tower aeration will be evaluated in this task. Assessment of treatment technologies will be assessed based on percent removal of radon.

12.2 Experimental Objectives

The objectives of this task are to demonstrate:

- appropriate operational conditions for the air-stripping equipment;
- radon removal achieved by the air-stripping technology; and
- necessary cleaning or equipment replacement during process operation.

Raw water quality shall be measured prior to system operation and then monitored every two weeks during the 60-day testing period at a minimum. It should be noted that the objective of this task is not process optimization, but rather verification of air-stripping operation at the operating conditions specified by the Manufacturer, as it pertains to percent removal of radon.

12.3 Work Plan

Determination of ideal aeration operating conditions for a particular water may require as long as one year of operation. For this task the Manufacturer shall specify the operating conditions to be evaluated in this Plan and shall supply written procedures on the operation and maintenance of the air stripping system as outlined previously. For this task the Manufacturer shall specify the operating conditions to be evaluated in the Verification Testing Plan and shall supply written procedures on the operation and maintenance of the air-stripping system. Each set of operating conditions shall be maintained for the 60-day testing period (24-hour continuous operation). The Manufacturer shall specify the primary hydraulic loading rate at which the equipment is to be verified. Additional operating conditions can be verified in separate 60-day testing periods.

After set-up and "shakedown" of aeration equipment, air-stripping operation should be established at the hydraulic loading condition to be verified. Testing of additional operational conditions could be performed by extending the number of 60-day testing periods beyond the initial 60-day test period required by the Verification Testing Program at the discretion of the Manufacturer and their designated FTO.

Additional 60-day periods of testing may also be included in the Verification Testing Plan in order to demonstrate air-stripping performance under different raw water quality conditions. For aeration technologies, extremes of raw water quality can affect a contaminant's Henry's constant and therefore the air-stripper design. The Manufacturer shall perform testing with as many different water quality conditions as desired for verification status. Testing under each different water quality condition shall be performed during an additional 60-day testing period, as required above for each additional set of operating conditions. The testing runs conducted under this task shall be performed in conjunction with finished water quality. With the exception of additional testing periods conducted at the Manufacturer's discretion, no additional air-stripping test runs are required for finished water quality.

12.4 Air Stripping Removal Efficiencies

12.4.1 Operational Data Collection

Removal rates of radon from raw water will be assessed by the percentage of removal from the source water. Measurement of influent raw water flow and finished water flow shall be collected at a minimum of three times per day. Table 12.1 is an example of a daily operational data sheet for an air-stripping system. This table is presented for informational purposes only. The actual forms will be submitted as part of the text plan and may be site-specific.

Water quality should be analyzed prior to start-up and then every two weeks for the parameters identified in Table 12.2, except for radon, which will be monitored prior to start-up and then weekly. Power usage for operation of the air-stripping equipment (pumping requirements, power factor, etc.) shall also be closely monitored and recorded by the FTO during the 60-day testing period. Power usage shall be estimated by inclusion of the following details regarding equipment operation requirements:

- pumping requirements;
- size of pumps;
- name-plate;
- voltage;
- current draw;
- power factor;
- peak usage; etc.

In addition, measurement of power consumption, chemical consumption shall be quantified by recording day tank concentration, daily volume consumption and unit cost of chemicals.

12.4.2 Raw Water Quality Limitations

The characteristics of raw waters used during the 60-day testing period (and any additional 60-day testing periods) shall be explicitly stated in reporting the removal data for each period. Accurate reporting of such raw water characteristics is critical for the Verification Testing Program, as these parameters can substantially influence the range of aeration performance and treated water quality under variable raw water quality conditions.

- Evaluation criteria and minimum reporting requirements.
- Plot graph of raw and finished radon concentrations over time for each 60-day test period.
- Plot graph of removal of radon over time for each 60-day test period.

TABLE 12.1: Daily Operations Log Sheet for an Air-Stripping Technology

Date:

Parameter	**Measurement 1**	**Measurement 2**	**Measurement 3**
Time			
Initial			
Air			
Q (cfm)			
T (°C)			
Raw Water			
Q_{raw} (gpm)			
$Radon_{raw}$ (pCi/L)			
pH_{raw} (before pretreatment)			
pH_{raw} (after pretreatment)			
T_{raw} (°C)			
Finished			
Q_{fin} (gpm)			
$Radon_{fin}$ (pCi/L)			
Removal $(Radon_{raw}-Radon_{fin})/Radon_{raw}$ (%)			

TABLE 12.2: Operating and Water Quality Data Requirements for Air-Stripping Processes

Parameter	Frequency for Sampling
Raw Water Flow	3 / Daily
Finished Water Flow	3 / Daily
List Each Pretreatment Chemical Used, And Dosage	Daily Data Or Monthly Average
Hours Operated Per Day	Daily
Hours Operator Present Per Day	Monthly Average
Power Consumption (kWh/Million Gallons)	Monthly
Independent check on rates of flow	Weekly
Verification of chemical dosages	Monthly
Feed Water and Finished Water Characteristics	
Radon	Weekly
Temperature	Every two weeks
pH	Every two weeks
Iron	Every two weeks
Manganese	Every two weeks
Total Alkalinity	Every two weeks
Total Hardness	Every two weeks
Calcium Hardness	Every two weeks
TDS/Conductivity	Every two weeks
Turbidity	Every two weeks
Coliforms	Every two weeks
HPC	Every two weeks

13.0 TASK 6: FINISHED WATER QUALITY

13.1 Introduction

Water quality data shall be collected for the raw and finished water as provided previously in Table 12.2. At a minimum, the required sampling shall be one sampling at start-up and two sampling events per month while raw water samples are collected. Water quality goals and target removal goals for the aeration equipment should be proven and reported in the FOD.

13.2 Objectives

The objective of the entire effort is to verify the Manufacturer claims. A list of the minimum number of water quality parameters to be monitored during equipment Verification Testing is provided in Table 12-2. The actual water quality parameters selected for testing and monitoring shall be stipulated in the FOD.

13.3 Work Plan

The FOD shall identify the treated water quality objectives to be achieved in the Statement of Performance Capabilities of the equipment to be evaluated in the Verification Testing Program. The FOD shall also identify in the Statement of Performance Capabilities the radon removal that shall be monitored during equipment testing. The Statement of Performance Capabilities prepared by the FOD shall indicate the range of water quality under which the equipment can be challenged while successfully treating the contaminated water supply.

It should be noted that many of the packaged and/or modular drinking water treatment systems participating in the Air-Stripping Verification Testing Program will be capable of achieving multiple water treatment objectives. Although this Air-Stripping Process Plan is oriented towards removal of radon, the Manufacturer may want to look at the treatment systems removal capabilities for additional water quality parameters.

Many of the water quality parameters described in this task shall be measured on-site by the NSF-qualified FTO. A state-certified or third party- or EPA- accredited laboratory shall perform analysis of the remaining water quality parameters. Representative methods to be used for measurement of water quality parameters in the field are described in Table 13.1. Where appropriate, the Standard Methods reference numbers and USEPA method numbers for water quality parameters are provided for both the field and laboratory analytical procedures.

For the water quality parameters requiring analysis at an off-site laboratory, water samples shall be collected in appropriate containers (containing necessary preservatives as applicable) prepared by the state-certified or third party- or EPA- accredited laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, including chain-of custody requirements, as specified by the analytical lab.

TABLE 13.1: Water Quality Analytical Methods

Parameter	AWWA Method [1]	EPA Method [2]
Radon	7500-Rn	---
Temperature	2550	170.1
pH	4500-H^+	150.2
TDS/Conductivity	2510	120.1
Turbidity	2130	180.1
Total Alkalinity	2320	310.2
Total Hardness	2340	130.2
Calcium Hardness	3500-Ca	215.2
Iron	3500-Fe	236.1
Manganese	3500-Mn	243.1
Coliforms	9222	---
HPC	9215	---

1) AWWA, Standard Methods for the Examination of Water and Wastewater, 20th Edition, 1998.

2) EPA, Methods and Guidance for Analysis of Water, EPA 821-C-97-001, April 1997.

13.4 Analytical Schedule

13.4.1 Removal of Radon

During the steady-state operation of each aeration testing period, radon mass balances shall be performed on the raw and finished water in order to determine the radon removal capabilities of the air-stripping system.

13.4.2 Raw Water Characterization

At the beginning of each aeration testing period, the raw water and finished water shall be characterized at a single set of operating conditions by measurement of the water quality parameters identified in Table 12.2.

13.4.3 Water Quality Sample Collection

Water quality data shall be collected at established intervals during each period of aeration testing. The minimum monitoring frequency for the required water quality parameters is once at start-up and weekly for radon and every two weeks for the remaining water quality parameters. The water quality sampling program may be expanded to include a greater number of water quality parameters and to require a greater frequency of parameter sampling.

13.4.4 Raw Water Quality Limitations

The characteristics of feedwater encountered during each 60-day testing period shall be explicitly stated. Accurate reporting of such raw water characteristics such as those identified in Table 12.2 are critical for the Verification Testing Program, as these parameters can substantially influence aeration performance.

13.5 Evaluation Criteria and Minimum Reporting Requirements

- Removal or reduction of radon
- Water quality and removal goals specified by the Manufacturer

14.0 TASK 7: QUALITY ASSURANCE/QUALITY CONTROL

14.1 Introduction

Quality assurance and quality control (QA/QC) of the operation of the aeration equipment and the measured water quality parameters shall be maintained during the Equipment Verification Testing Program.

14.2 Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures during the Equipment Verification Testing Program. Maintenance of strict QA/QC procedures is important, in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

14.3 QA/QC Work Plan

Equipment flow rates and associated transmitter signals should be calibrated and verified on a routine basis. A routine daily walk through during testing shall be established to check that each piece of equipment or instrumentation is operating properly. Particular care shall be taken to verify that chemicals are being fed at the defined flow rate, and into a flow stream that is operating at the expected flow rate. This will provide correct chemical concentrations in the flow stream. In-line monitoring equipment such as flow meters, etc. shall be checked monthly to verify that the readout matches with the actual measurement (i.e. flow rate) and that the signal being recorded is correct. The items listed are in addition to any specified checks outlined in the analytical methods.

When collecting water quality data, all system flow meters will be calibrated using the classic bucket and stopwatch method where appropriate. Hydraulic data collection will include the measurement of the finished water flow rate by the "bucket test" method. This would consist of filling a calibrated vessel to a known volume and measuring the time to fill the vessel with a stopwatch. This will allow for a direct check of the system flow measuring devices.

14.3.1 Daily QA/QC Verification

- On-line temperature meters (check and verify components)

- On-line pH meters (check and verify components)

14.3.2 Monthly QA/QC Verification

- Pretreatment chemical feed pump flow rates (verify volumetrically over a specific time period)
- On-line flow meters/rotometers (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings)
- Air filters (verify good condition of air filters, replace if necessary)
- Diffuser conditions (verify good condition of diffuser, replace if necessary)
- Packing condition (verify good condition of packing, treat or replace if necessary)
- Piping (verify good condition of all piping and connections, replace if necessary)

14.4 Analytical Methods

Use of either bench-top field analytical equipment will be acceptable for the verification testing; however, on-line equipment is recommended for ease of operation. Use of on-line equipment is also preferable because it reduces the introduction of error and the variability of analytical results generated by inconsistent sampling techniques. However, standard and uniform calibration and standardization techniques that are approved should be employed. Table 13.3 lists American Water Works Association (AWWA) and EPA standard methods of analysis.

15.0 TASK 8: COST EVALUATION

This Plan includes the assessment of costs of verification with the benefits of testing air-stripping technologies over a wide range of operating conditions. Therefore, this Plan requires that one set of operating conditions be tested over a 60-day testing period. These equipment Verification Tests will provide information relative to systems, which provide desired results and the cost, associated with the systems. These parameters will be used with the equipment Verification Test costs to prepare cost comparisons if pilot scale units are provided for Verification Testing purposes.

Operation and maintenance (O & M) costs realized in the equipment Verification Test can be utilized for calculating cost estimates. O & M costs for each system will be determined during the equipment Verification Tests. The O & M costs that will be recorded and compared during the Verification Test include:

- Labor;
- Electricity;
- Chemical dosage; and
- Equipment replacement frequency.

The capital and O & M costs will vary based on geographic location.

O & M costs should be provided for each air-stripping system that is tested. In order to receive the full benefit of the equipment Verification Test Programs, these costs should be considered along with quality of system operations. Other cost considerations may be added to the cost tables presented in this section as is needed prior to the start-up of the Verification Tests. A summary of O & M costs are outlined in Table 15.1.

Table 15.1 Operations and Maintenance Cost

Cost Parameter	Specific Utility Values
Labor rate + fringe ($/personnel-hour)	
Labor overhead factor (% of labor)	
Number of O&M personnel hours per week	
Power Consumption (kWh/Million Gallons)	
Electric rate ($/kWh)	
Cost of Packing Materials ($)	
Packing Material or Aeration Equipment Replacement (%/year)	
Cost of Chemicals ($)	
Chemical Dosage (per week)	
O&M Cost ($/Kgal)	

16.0 SUGGESTED READING

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